COMPARATIVE ANALYSIS OF THREE-PHASE INDUCTION MOTOR FED FROM BALANCED AND UNBALANCED POWER SUPPLY

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ABSTRACT

In a three-phase system, unbalance voltage introduce when the magnitudes of phase voltages and the phase angles differ from the balanced conditions, or both. Unbalanced voltage factor have own importance when we are studying the impact of unbalance voltage on the behavior of three-phase induction machines.

Problems like over & under voltages, oscillations, high losses and disturbance in phase angle are the key problem of unbalance voltage factor. Searching these abnormal conditions in the machine have major importance in the electrical machine. In this paper the effect of the balance and unbalanced voltages on the motor performance, have been investigated just like rotor and stator current, speed, electromagnetic torque graphs.

KEYWORDS: Stator Current, Rotor Current, Speed, Torque, Induction Motor, Unbalanced Supply

INTRODUCTION

Voltage unbalance is combination of under- or over voltage is known as a power quality problem at the electricity distribution level. This phenomenon is present in three-phase electrical power system. If the voltages of all phase are balanced at the transmission levels it may be possible voltages at the utilization level can become unbalanced due to the unequal load impedances, improper transposition of transmission lines, Absence of neutral in three phase star connection, unsymmetrical transformer winding, open delta connection of transformer, larger single or two phase loads, blown fuses on three-phase capacitor banks. An excessive level of unbalance in voltage can have serious/ enormous impacts on mains connected induction motors. A lot of efforts have been reported in literature the adverse effects on induction motor performance under unbalanced voltage supply condition. An AC (Alternating Current) induction motor is the simplest and most rugged electric motor and consists of two assemblies - a stator and a rotor. The interaction of currents flowing in the rotor bars and the stators' rotating magnetic field generates a torque. In an actual operation, the rotor speed always lags the magnetic field's speed, allowing the rotor bars to cut magnetic lines of force and produce useful torque.

The difference between *the synchronous speed of the magnetic field* and *the shaft rotating speed* is slip - and would be some number of rpm or frequency.

There are two types of rotor windings: squirrel-cage rotor and form-wound rotor. The induction ac motor derives its name from currents flowing in the secondary member (rotor) that are induced by alternating currents flowing in the primary member(stator).The combined electromagnetic effects of the stator and rotor currents produce the force to create rotation.

In this paper, comparative study made on three-phase induction motor under balanced and unbalanced voltage supply, using Simulink. Simulink is the extremely powerful tool of MATLAB. The phase currents, the deliverable power to the motor, stator current and efficiency of the motor are propose. In order to analyze the performance of a three phase induction motor, symmetrical components analysis is must be use. In this method, positive and negative sequence equivalent circuits, as shown in Figure 2, are utilized to calculate different parameters of the machine under unbalanced voltage operation.

When we apply unbalanced voltages it produces negative sequence current and it produces a backward rotating field and forward rotating field produced by the positive sequence one. The interaction of forward rotating field backward rotating field produces pulsating electromagnetic torque and ripple in speed.

In this condition induction motor as over- heated and, hence burn. When we apply voltage unbalance some negative effects affected to the performance of three-phase induction motors include: more losses, temperature rise, insulation life less, developed torque and life reduce reduction of the machine. In this case consumer will pay higher electricity charge for same work done.

The induction motors are widely used in industrialized, saleable and housing applications and most of them are connected directly to electric power. So it is most important to clear the effect of unbalance voltage on the performance of IM.

The Equivalent Circuit of an Induction Motor for Unbalanced Supplies

Why motor torque decreases it can be explained by equivalent circuit. The positive sequence torque seems the torque of an induction motor operating on a balanced supply. The backward rotating field produced by the negative sequence currents produces a negative torque. The net shaft torque produced by the machine will be comparatively less than produced by balanced supply because of the magnitude of negative sequence is not negligible.

Graphical Representation of the Positive and Negative Sequence Torques
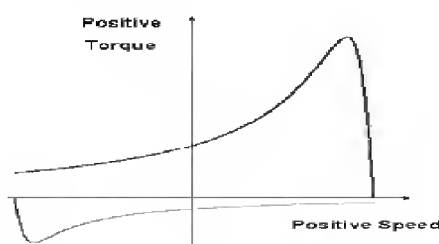

Figure 1: Graphical Representation of the Positive and Negative Sequence Torques of an Induction Motor Subjected to Unbalanced Supply Voltages

Let us consider Rotor speed and the slip of a motor for onward motion denoted by N, s respectively. It is well identified that onward component phase sequence is identical to that of the supply, due to onward component magnetic field induces, rotation direction of these component are same as the motor shaft. The per phase equivalent circuit which is construct for the rotating field, is the same as equivalent circuit of an induction motor

The magnetic field produces reverse component which is rotates in the opposite direction with respect to the rotor, where the slip is denoted by 2-s. The reverse magnetic field should generate at minimum amplitude, because due to this magnetic field a large amount of power loss occur in the motor. Three-phase power system can be supposed as

symmetrical when the amplitude of reverse magnetic field is less than that of 5% of the onward component. Zero component currents are not generated any rotating field, because the direction of each phase is same.

However a motor fed from V_1, V_2, V_3 unbalanced voltage supply can be considered to consist of two motors operating individually. The first motor operates from onward component of balanced system at V1 voltage with s slip in usual rotation direction. The second motor operates from reverse component of balanced system at V2 voltages with 2-s slip in opposite direction. The per phase equivalent circuits are shown in Figure 1. The per phase equivalent circuit for the onward component is obtained by placing s as the s slip, I_1 as the stator current and I_2 as the rotor current in the equivalent circuit of symmetrical components of an induction motor operating at unbalanced supply.
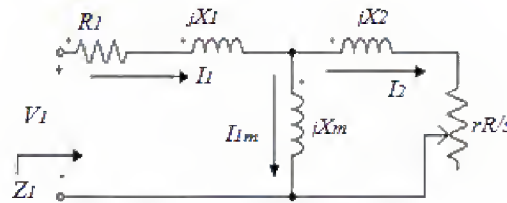

Figure 2(a): Per Phase Equivalent Circuit for the Onward Component

Similarly, the equivalent circuit for the reverse component can be derived, where 2-s, I_1, I_2 represent the backward/ reverse slip, the stator current and the rotor s respectively as illustrated in Figure 2a and Figure. 2b.
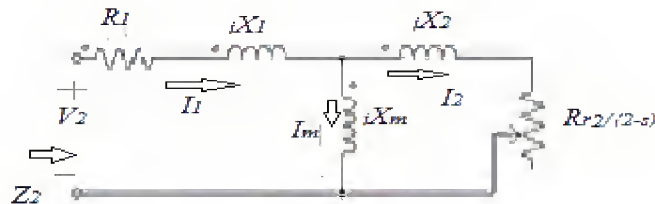

Figure 2(b): Per Phase Equivalent Circuit for the Reverse Component

Simulation / MATLAB Model

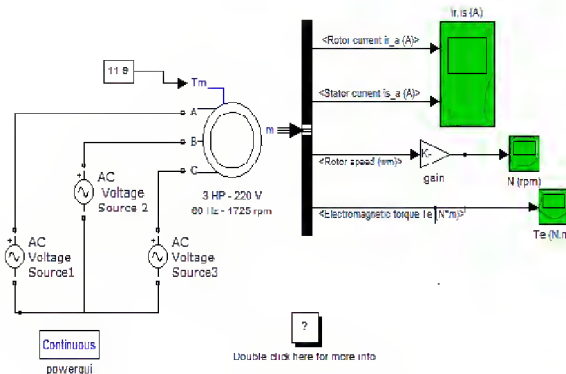All the analysis done using this Matlab model shown in figure 2c

Figure 2(c): MATLAB Model

Comparison of Rotor Current & Stator Current, Speed, Torque of I.M. under Balanced and Unbalanced Condition Balanced Case

In this part we examine balanced operating condition. It is essential to achieve this to build up a reference for

comparison purposes. This model has been simulated. In normal condition, motor was supplied by its rated voltage which is 220 volts peak for each phase. The voltages applied are as follows:

$V = 220\angle\ 0\ f = 60\ Hz$

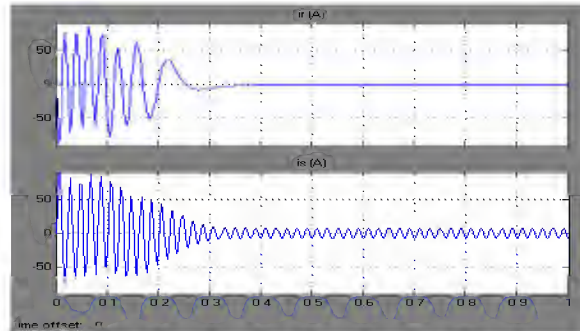Simulation results are depicted as in figure 3a & figure 3b

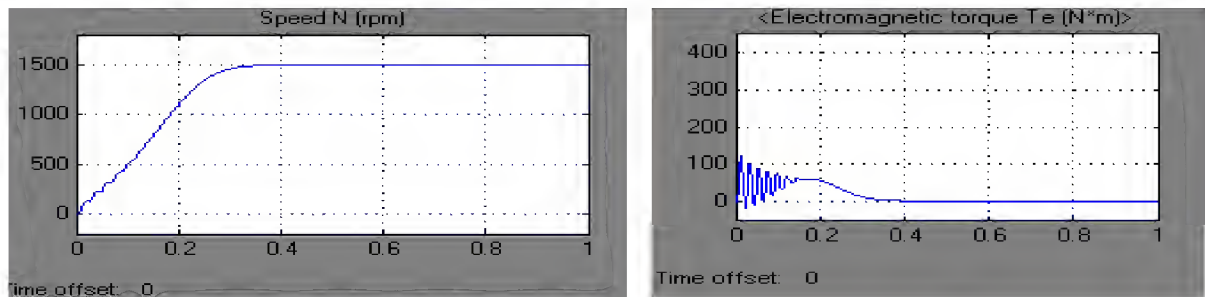**Figure 3(a): Stator Phase 'a' Currents, the Rotor Phase 'a' Current against Time**

Figure 3(b): Rotor Speed, Electromagnetic Torque Te (N-m) against Time t (sec)

Unbalanced Cases

Here unbalance in the phase and the magnitude of the voltage has been considered. In order to model the electrical motor symmetrical components can be used.

Unbalanced in the Voltage Magnitude

Case 1(a): In this part the unbalance in magnitude of the voltage has been considered. In order to model the electrical motor symmetrical components can be used. A wide variety of research has been done on modeling of unbalanced condition.

$Va = 230\angle\ 0\ Vb = 231\angle\ -120\ Vc = 235\angle\ -240\ f = 60\ Hz\ P = 3\ HP\ Ns = 1725\ rpm$
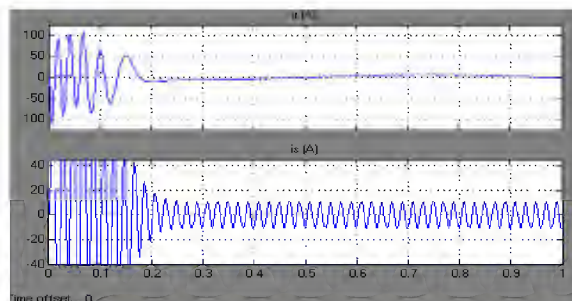

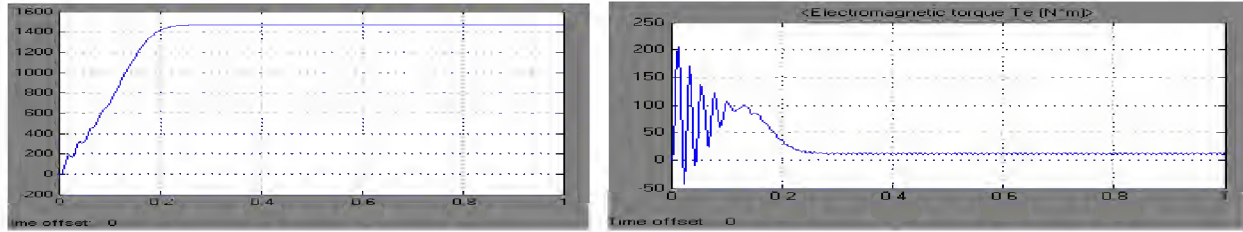**Figure 4(a): Stator Phase 'a' Currents, the Rotor Phase 'a' Current against Time**

Figure 4(b): Rotor Speed, Electromagnetic Torque Te (N-m) against Time t(sec)

Case 2: In this case an unbalance of 10% of the rated voltage is assumed for phase B and C voltages respectively. So, the value of the voltages for phases A, B and C would be as follows:

$$Va = 230\angle 0, V_b = 230*0.90\angle -120, Vc = 230*0.90\angle -240, f = 60 \text{ Hz } P = 3 \text{ HP Ns} = 1725 \text{ rpm}$$
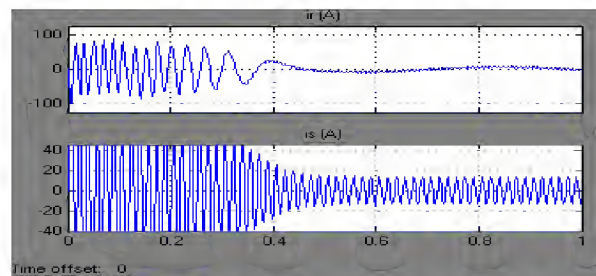

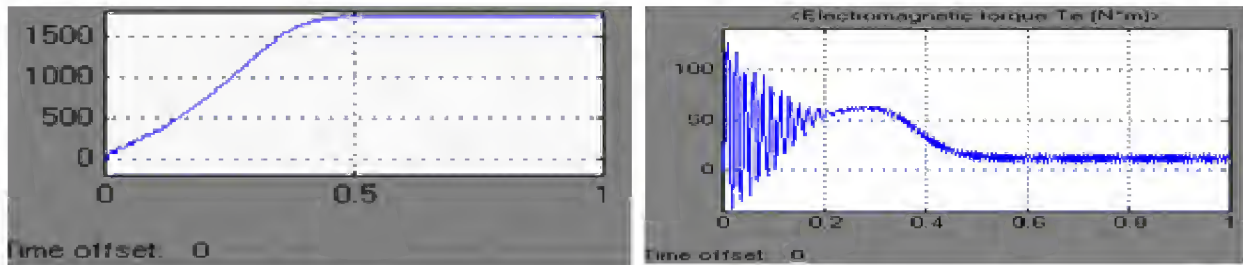**Figure 5(a): Stator Phase 'a' Currents, the Rotor Phase 'a' Current against Time**

Figure 5(b): Rotor Speed, Electromagnetic Torque Te(N-m) against Time t(sec)

Case3: Unbalance in the Voltage Magnitude Case 2

In this case an unbalance of 10% and 20% of the rated voltage is assumed for phase B and C voltages respectively. So, the value of the voltages for phases A, B and C would be as follows:

$$Va = 230\angle 0, Vb = 230*0.90\angle -120, Vc = 230*0.80\angle -240 \text{ f} = 60 \text{ Hz } P = 3 \text{ HP Ns} = 1725 \text{ rpm}$$
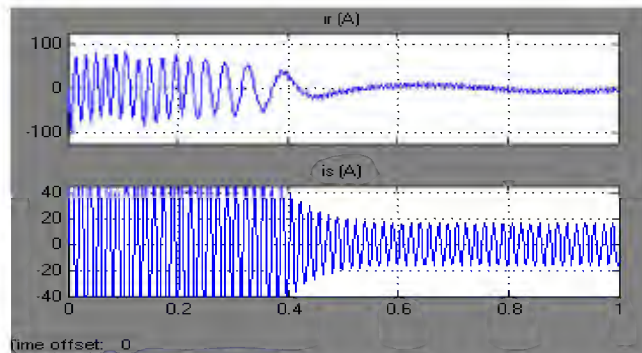

Figure 6(a): Stator Phase 'a' Currents, the Rotor Phase 'a' Current against Time
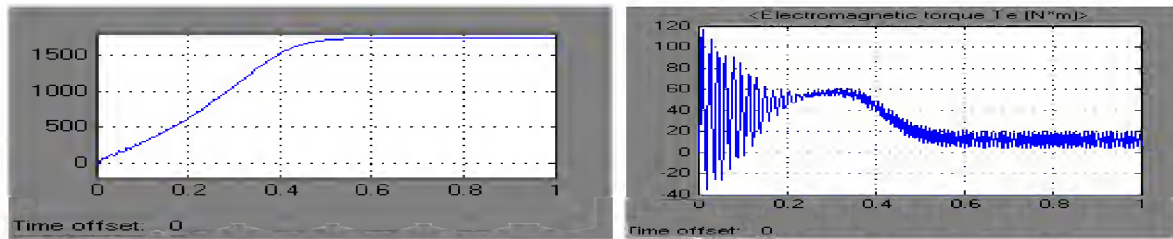
Figure 6(b): Rotor Speed, Electromagnetic Torque Te (N-m) against Time t (sec)

Unbalance in the Voltage Magnitude and Phase

In this case an unbalance of 10% of the rated voltage is assumed for phase B and C voltages respectively. So, the value of the voltages for phases A, B and C would be as follows:

$$Va = 230\angle 0 \ Va = 230*0.90\angle 216 \ Va = 230*0.90\angle 132 \ f = 60 \text{ Hz P= 3 HP Ns= 1725 rpm}$$
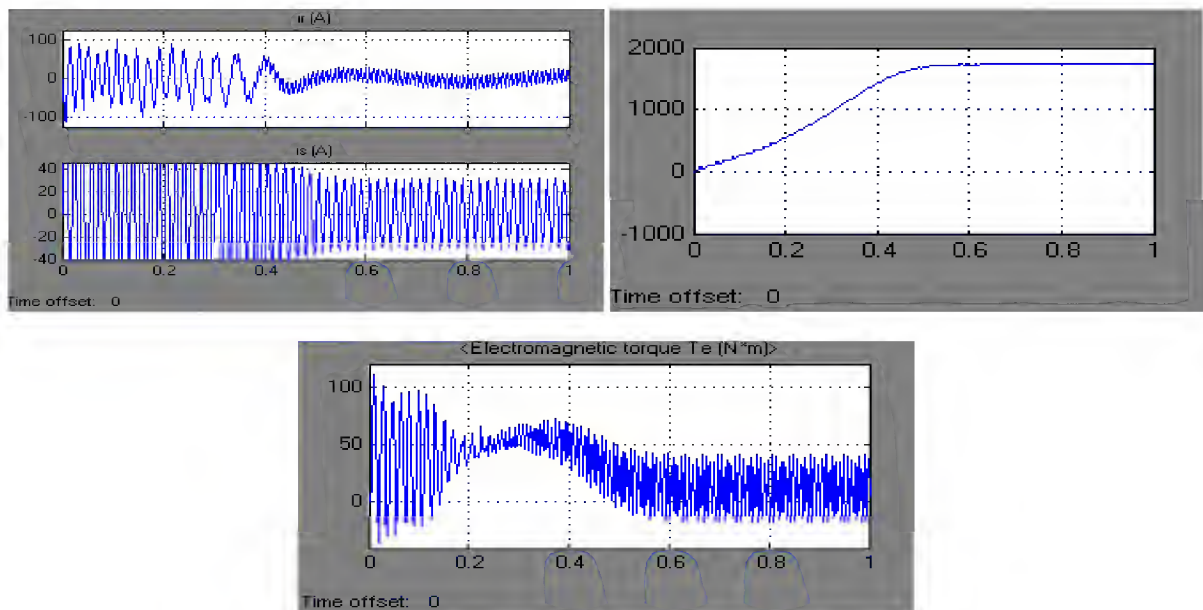

Figure 7: Rotor and Stator Current, Speed and Electromagnetic Torque Te (N-m) against Time t (sec)

CONCLUSIONS

Here a new way of action is presented to demonstrate the steady-state performance of three phase induction motors under unbalanced conditions focusing on the stator and rotor current, speed, electromagnetic torque. As a final point we have concluded that three-phase induction motor if operating on unbalance voltage degrades the performance and shortens the life of a three-phase motor. By increasing the unbalance voltage, the maximum amplitude of the current and torque are notably increased. It is known by us that voltage unbalance causes extra loads to the utilities and additional charges to consumers for same on balanced supply. Also it can be seen that efficiency of the motor under three-phase unbalanced voltage is inferior as compare to efficiency at normal condition. Excessive losses, heating, noise, vibration, torsional pulsations, slip, and motor accelerating torque, are due to unbalancing in the voltage. An extreme level of voltage unbalance can have major impacts on mains connected induction motors. Due to current unbalance excessive losses increases in the stator and rotor by which loss of production occur. Although induction motors are designed in this way it tolerates a small level of unbalance.

REFERENCES

1. Buksnaitis J. Methods for Determination of Winding Factors of Alternating-Current Electric Machines // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No.1 (89). – P. 83–86.

2. Krause, P.c.: Analysis of Electric Machinery" McGraw-Hill Book company, New York,1986.

3. Wolfram, S.: Mathematica, 2nd Ed; New York/USA; Addison-Wesley Publ. Co. Inc;1988.

4. Bounadja M., Belmadani B., Belarbi A. W. A Combined Stator Vector Control – SVM-Direct Torque Control for High Performance Induction Machine Drives // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 8(96). – P. 51–54.

5. Kersting W. H. Phase Frame Analysis of the Effects of Voltage Unbalance on Induction Machines // IEEE

6. Transaction on Indutry Aplications, 1997. – Vol. 33. - No. 2.

7. "The MATLAB Compiler User's guide," in Math works handbook, Math works, 1994.

8. M. H. J. Bollen, Understanding Power Quality Problems Voltages and Interruptions. Piscataway, NJ: IEEE Press, 1999.

9. D. O. Koval, R. A. Bocancea, K. Yao, and M. B. Hughes, "Canadian national power quality survey: Frequency and duration of voltage sags and surges at industrial sites," IEEE Trans. Ind. Appl., vol. 34, no. 5, pp. 904–910, Sep./Oct. 1998.

10. C. J. Melhorn and M. F. Mc Granaghan, "Interpretation and analysis of power quality measurements," IEEE Trans. Ind. Appl., vol. 31, no. 6, pp. 1363–1370, Nov./Dec. 1995.

11. A.V. Jouanne, B. Banerjee, "Assessment of voltage unbalance," IEEE Trans. Power Delivery, Vol. 16, No. 4, October 2001, pp. 782- 790.

12. O. Souto, J. Oliveira, and L. Neto, "Induction motors thermal behavior and life expectancy under non ideal supply conditions," in IX Int. Conf. Harmonics and Quality of Power, Orlando, FL, 2000

13. Alwash, J.H.H., Ikhwan, S.H., "Generalised approach to the analysis of asymmetrical three-phase induction motors", IEE Proceedings Electric Power Applications, Volume: 142, Issue: 2, Page(s): 87-96, March 1995.

14. Smith, A.C., Dorrell, D.G., "Calculation and measurement of unbalanced magnetic pull in cage induction motors with eccentric rotors. I. Analytical model", IEE Proceedings Electric Power Applications, Volume: 143, No. 3, Page(s): 193-201, May 1996.

15. J. Oyama, F. Profumo, E. Muljadi, and T. A. Lipo: Design and performance of a digitally based voltage controller for correcting phase unbalance in induction machines, IEEE Trans. on IA Vol. 26 no 3, pp. 425-433.

16. Hirotsuka, K. Tsuboi, and F. Ueda, "New Calculation Method and Characteristics for the Induction Motor under Unbalanced Voltage Condition," Institute of Electrical Installation Engineers of Japan, Vol. 26, No. 3, pp. 215–219, March 2006

17. J. E. Williams, "Operation of 3-phase induction motors on unbalanced voltages", IEEE Trans. on Power Apparatus and Systems, Vol. 73, Pt. III, April 1954, pp. 125-133.

18. M. M. Berndt and N. L. Schmitz, "Derating of polyphase induction motors operated with unbalanced line voltage", AIEE Trans. On Power Apparatus and Systems, Vol. 81, Feb. 1963, pp. 680-686.

19. NEMA Standard MG1-Motor and Generators, 1987.

20. C. Y. Lee, "Effects of unbalanced voltage on the operation performance of a three-phase induction motor," IEEE Trans. on Energy Conversion, Vol. 14, No. 2, 1999, pp. 202- 208.

21. P. Pillay, P. Hoffmann and M. Manyage, "Derating of induction motors operating with a combination of unbalanced voltages and over or under voltages", IEEE Trans. on Energy Conversion, Vol. 17, No. 4, December 2002, pp. 485-491.

22. Faiz, H. Ebrahimpour and P. Pillay, "Influence of unbalanced voltage on the steady-state performance of a three phase squirrel-cage induction motor", Accepted for publication in IEEE Trans. on Energy Conversion.

23. Lie Xu, Yi Wang, "Dynamic modeling and control of DFIG-Based wind turbines under unbalanced network conditions", IEEE trans. on Power Systems, vol.22, pp. 314 –323, 2007.

24. T.K.A. Brekken, N. Mohan, "Control of a doubly fed Induction wind generator under unbalanced grid voltage conditions", IEEE trans. on Energy Conversion, vol.22, pp. 129– 135, 2007.

APPENDICES

The simulations have been carried out using the below motor data gotten from the open and short circuit tests of the induction motor under study: 3hp,220V, 4Poles, 60Hz

Rs = 0.435Ω, L1s =2.2mH, L1r = 2.0mH, Lm =69.31mH, R_r = 0.816Ω, N=1725 rpm